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Overview of Combustion Emissions in the United States

Alliance Technologies Corp., Chapel Hill, NC

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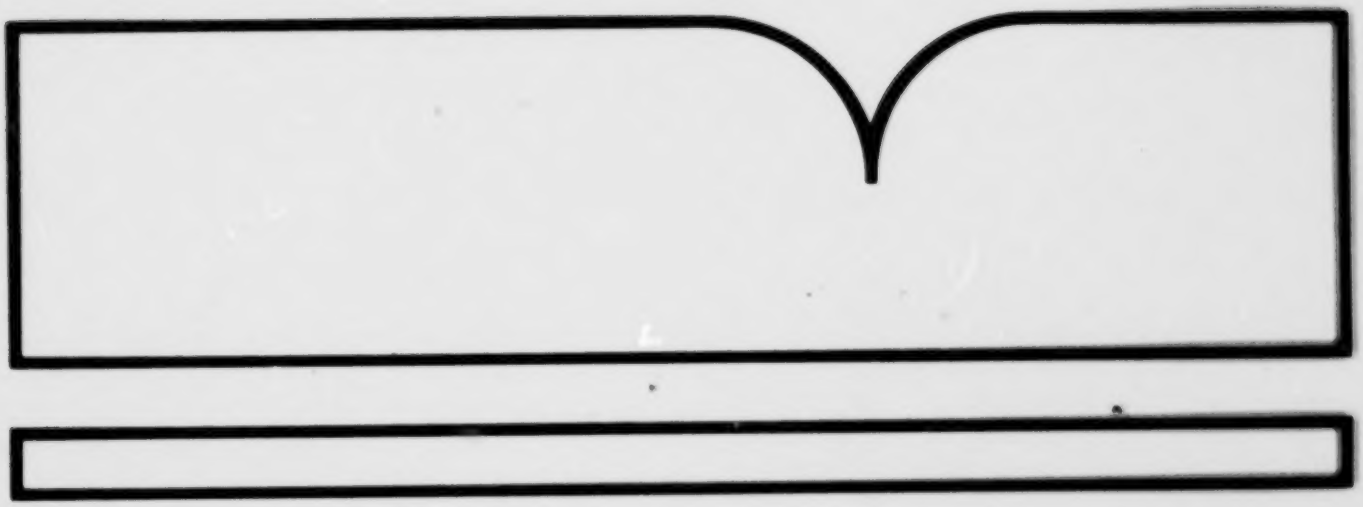

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16. ABSTRACT The paper summarizes combustion emissions using the results of past and ongoing research programs in emissions trends and detailed inventories. Due to the availability of data and the distribution of total U.S. emissions, SO2 and NOx are emphasized. The discussion includes both magnitude and transport emissions parameters, both of which are vital to understanding the impacts of these emissions. The paper initially reviews the general methodologies employed by the referenced research, then summarizes results regarding aggregated, combustion emissions categories. Finally, brief conclusions are drawn from the presented information. Combustion categories are the most significant sources of SO2 and NOx emissions. Utilities contributed nearly 70% of the 1985 anthropogenic emissions of SO2. The two major sources of NOx in 1985 were utilities and transportation. On the other hand, VOC emissions in 1985 came from combustion and non-combustion sources, principally evaporative fugitive sources, in approximately equal amounts. Detailed conclusions on specific emissions sources cannot be drawn from the trends data or the single year of detailed emissions presented in the paper. However, emissions trends analysis and detailed emissions inventories provide the tools necessary to begin the assessment of the fate and impacts of emissions in the environment.

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AN OVERVIEW OF COMBUSTION EMISSIONS IN THE UNITED STATES

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INTRODUCTION

Combustion emissions are specific to individual site and device parameters, including combustor type and design, operating conditions, fuel quality, control device operation, and maintenance practices. An overview of U.S. combustion emissions cannot examine each combustion source, but must aggregate combustion processes to permit a meaningful summary and analysis of the data on a national scale.

The U.S. Environmental Protection Agency (EPA) employs several tools to analyze emissions and their transport through the atmosphere. These tools include trend analyses, detailed emissions inventories, individual source tests, and emissions species profiles developed from source tests. The latter two methods are too detailed for an overview, because they look at specific emissions test data to examine particular species from specific combustors or combustor types. The first two methods can be used to gain an overview of combustion sources. Trend analyses allow emissions magnitudes, transport parameters, and major source categories to be examined over time without reference to individual sources. Detailed inventories include individual plants and combustors above a specified emissions level and allow the linkage of particular source emissions with transport parameters for each source. The standard format of the detailed data base allows the data to be aggregated to less detailed levels. These two "broadbrush" techniques, trend analyses and detailed emissions inventories, are used to summarize combustion emissions for this paper.

Because the eventual purpose of this research is to assess the impacts of emissions, parameters needed to calculate the transport of emissions are as

critical as the magnitude of emissions. The detailed inventory is useful because it allows one to link emissions and transport parameters. With this information, the fate of pollutants can be explored through atmospheric transport modeling and ambient monitoring. Information on the chemical constituents of emissions allows analysis of potential health and ecological effects.

Emissions sources are divided into two categories: stationary (e.g., boilers) and area/mobile sources (e.g., automobiles). These categories are treated differently by trends and detailed data bases. The trends methodologies distinguish only between stationary and mobile sources. The detailed methodology includes those stationary sources which are too small or numerous for an individual inventory (at the national level) as area sources, in addition to mobile sources. Stationary sources emitting less than 25 tons* per year (TPY) of NO_x (nitrogen oxides), SO_2 (sulfur dioxide), and VOC (volatile organic compounds) are therefore included in the area source category.

Stationary sources have been grouped into categories for analysis based on their contribution to total anthropogenic U.S. SO_2 and NO_x emissions. The major categories include utilities, industrial combustion, and other combustion sources (e.g., commercial combustion and waste disposal). Data are also presented by fuel type and, within the industrial category, by industry sector. Area source categories presented here include transportation, residential combustion, and industrial combustion.

*For readers more familiar with metric units, a table of conversion factors follows the references.

In reviewing trends data, it is sometimes not possible to separate combustion and non-combustion emissions, particularly in the industrial and miscellaneous categories, because process-level detail is not available at this level of aggregation. Such a separation is possible in the detailed data base and is explained in the following sections.

This paper will summarize combustion emissions using the results of past and ongoing research programs in emissions trends and detailed inventories. Due to the availability of data and the distribution of total U.S. emissions, SO_2 and NO_x will be emphasized. The discussion will include both magnitude and transport emissions parameters. The paper will initially review the general methodologies employed by the referenced research, then summarize results regarding aggregated, combustion emissions categories. Finally, brief conclusions will be drawn from the presented information.

METHODOLOGY

Combustion sources contribute significantly to the total SO_2 and NO_x emitted by anthropogenic sources. Major combustion sources include electric utilities, industrial boilers and internal combustion engines, smelters, natural gas engines and turbines, industrial process heaters, iron and steel furnaces, kilns, incinerators, residential fuel combustion, and transportation sources. This paper presents an overview of long-term historic trends in combustion emissions and a detailed breakdown of current (1985) emissions from combustion sources. Methodology and data sources for these two analyses are discussed below.

Historic Inventory

The historic inventories permit identification of aggregated emissions over many years. In order to provide consistency to the estimates and trends, the methodology is limited to the use of data that are available over the entire time frame. The focus of the overview is on major categories of emissions to gain perspective on their emissions trends over time.

Three major historic data bases have been developed to examine trends for SO_2 and NO_x emissions.(1,2,3) The primary data set used here, Historic Emissions of Sulfur and Nitrogen Oxides in the United States from 1900 to 1980, Volume I. Results(1), was developed to provide long-term estimates of emissions to allow comparison with existing, long-term effects research. These data are resolved to the state level for 5 year intervals and are divided among approximately 30 sectors encompassing all combustion emissions. In order to present long-term trends, this paper will rely principally on this historic inventory from 1900 to 1980. A brief review of the methodology is provided below. This work was extended to encompass VOC emissions from 1900 to 1985 and those data are also used here.(4) All data are resolved to the state level and include total anthropogenic emissions by major sector.

Combustion-derived emissions in the historic SO_2 and NO_x data base are broken down into major fuels. Annual quantities of emissions of SO_2 and NO_x were calculated for each of the contiguous 48 states and the District of Columbia. Emissions of each pollutant were estimated for every fifth year from 1900 to 1980. The time span from 1900 through 1980 was selected to allow a comparative study with historic environmental measurements. The 1985 data from similar trends studies were integrated to extend the analysis to 1985 for SO_2

and NO_x.(6) Five-year intervals were selected to indicate the emission trends sufficient for most effects studies and to develop a methodology that could be applied to all other years. The state level was selected because it provides the most complete and consistent body of information on an historic basis and collectively covers all geographic regions of the country. The basic steps involved in calculating state emissions of SO_2 and NO_x are listed below as an example of the methodology employed(1):

- Obtain national/state level information on fuel use,
- Allocate fuel quantity used by each source category,
- Develop/apply source category emission factors,
- Determine fuel sulfur content by state for each category, and
- Apportion/calculate emissions, after emissions controls.

For each state the estimates are based on the apparent annual consumption rate of fuels. The fuels include bituminous and anthracite coals, lignite, residual and distillate oil, natural gas, wood, gasoline, diesel fuel, and kerosene. The consumers of these fuels, which are also the emitters of SO_2 and NO_x, are categorized according to whether they are electric utilities, industrial boilers, commercial and residential furnaces, natural gas pipelines, highway vehicles, railroads, coke plants, smelters, vessels, or other major sources. Emissions were also estimated for wildfires, industrial processes (including in-process fuel combustion) based on production rates, and a miscellaneous source category. Collectively, these source categories account for all anthropogenic emissions in each state.

The state-level consumption and process data were multiplied by specially derived emission factors to yield estimates of uncontrolled emissions. The actual procedure varied somewhat depending on the usefulness and availability of information. In general, state-specific data were available for 1950-1980. Prior to 1950, these data were not always available, and national data were apportioned to the states.

Another historic data base, Estimated Monthly Emissions of Sulfur Dioxide and Oxides of Nitrogen for the 48 Contiguous States, 1975-1984,(2) has been developed to track emissions for major source categories monthly and annually. These data are based on the National Air Pollutant Emission Estimates, 1940-1984.(3) Emissions are allocated to each state based on state shares in the 1980 National Acid Precipitation Assessment Program (NAPAP) emissions inventory(5) and further disaggregated using monthly activity indices for various sectors. The three historic data bases differ chiefly in the temporal resolution, temporal extent, and category resolution.

Detailed Emissions Inventory

Detailed emissions data inventories contain highly resolved process, emissions, temporal, and spatial data not available from historic inventories. The detailed inventory permits analysis of the relationships between emissions at given sources, the transport and transformation of emissions, and their impact on the local or distant environment. Detailed inventories identify the relative importance of both emissions categories and individual sources.

The most comprehensive U.S. SO_2 and NO_x emissions inventories are the 1980 and 1985 NAPAP emissions data bases, which the states and EPA compiled for

NAPAP.(5) Both contain source-specific data and emissions estimates for their respective base years. These inventories are designed to permit analysis of relationships between emissions sources and regional air pollution problems (e.g., acid precipitation, ozone). The 1985 data base will be discussed here because it represents the most accurate and comprehensive national inventory of combustion sources in the U.S.

The 1985 emissions inventory is designed to provide anthropogenic emissions data for all significant stationary and area sources of SO_2, NO_x, and VOC in the U.S., as well as engineering parameters which affect the atmospheric transport of emissions. The inventory is divided into two major categories, point and area sources. Point sources are defined as sources that have precise location data and emit at least 25 tons per year (TPY) of a NAPAP priority pollutant (NO_x, SO_2, or VOC). Area sources comprise both mobile sources and point sources too small to list individually, because collecting point source data for every stationary source in the U.S. is impractical. Combustion sources reside in both categories.

The inventory contains estimates of emissions from approximately 100,000 stationary sources in the U.S. During the last decade, emissions from important process categories have been measured using standardized sampling techniques. The measurements have been compiled and analyzed for each category to develop emission factors for each of 3,300 industrial processes currently reported in the U.S. Many of these factors are contained in the EPA publication AP-42.(7) The emission factor is multiplied by the activity level of a stationary or area source over a given period of time to estimate emissions.

Area source emissions estimates are calculated by EPA using a series of computer programs in a "top-down strategy" which allocates national emissions estimates to the state and county levels. Approximately 100 area source categories are used to estimate emissions in each U.S. county.

The 1985 inventory focused on the following items: annual emissions estimates for SO_2, NO_x, and VOC; the maximum design rate and operating data; the Source and Standard Industrial Classification Codes (SCC and SIC); emissions control equipment and efficiencies; fuel characteristics; stack parameters; and location data. The 1985 data base contains estimates of SO_2, NO_x, and VOC, as well as two other criteria pollutants, CO (carbon monoxide) and PM (particulate matter), and four chemical species believed to play an important role in acid deposition (primary sulfate, hydrogen chloride, hydrogen fluoride, and ammonia).

Table 1 compares specifications for the 1900-1980 historic emissions data base and the 1985 NAPAP emissions data base.

RESULTS

Combustion-related emissions comprise more than 90 percent of total anthropogenic SO_2 and NO_x, and about 50 percent of total anthropogenic VOC in the 1985 emissions inventory. Due to the structure of both the historic and current inventories, it is not possible to entirely separate combustion and process emissions for all industrial processes. Certain processes (such as smelting, electric arc furnaces, and nitric acid production) produce SO_2 and NO_x emissions which are not directly combustion products. If emissions from

these and other industrial processes are considered combustion-related, nearly 100 percent of anthropogenic SO_2 and NO_x emissions arise from combustion.

In deciding which processes were sources of combustion emissions, the following criteria were used. Only those sources where a material is oxidized to provide heat or to destroy the bulk of the material were included. Chemical processes which use an oxidation reaction to produce an intermediate stream were not included. Thus, the SO_2 emissions of Claus sulfur recovery units and sulfuric acid production plants are not included, even though burning is used in these processes to produce an SO_2 feedstream. NO_x emissions from the catalytic oxidation of ammonia in the production of nitric acid are not included, nor are emissions from carbon black furnaces or charcoal kilns. Some major processes which are included in combustion emissions are refinery catalytic cracker regeneration, hydrogen sulfide gas incineration or flaring, and smelting furnaces. Smelting furnaces include emissions from fuels which are burned to produce heat as well as emissions of oxidized impurities from the ores. These emissions are not separable by the inventory. As a result, smelter SO_2 emissions are inordinately larger than their NO_x emissions due to the oxidation of sulfides.

Some VOC emissions occur as a result of incomplete combustion, although most are from non-combustion (evaporative) sources. VOC emissions are included here due to their importance in acid deposition chemistry. It is important to note that total emissions of SO_2 and NO_x are essentially the same as combustion emissions, but that the same is not true for VOC emissions. The major focus of this paper is therefore on SO_2 and NO_x emissions.

The results consider atmospheric transport parameters as well as emissions magnitudes. Both data types are important to assess the fate of emissions.

The critical atmospheric transport parameters include source location, stack height, exhaust gas flow rate, and temperature. In this paper, the historic and detailed inventories are analyzed in terms of stack height. The spatial distribution of major sources is presented for the detailed inventory.

Historic Trends

Total annual emissions of SO_2, NO_x, and VOC at 5 year intervals are plotted in Figure 1, along with Gross National Product (GNP) and population totals. The lines connecting the 5 year data points are shown only to indicate the trend, and do not represent actual data. NO_x emissions have increased more rapidly and more steadily than SO_2 or VOC emissions, rising from 3×10^6 tons in 1900 to a high of about 22×10^6 tons in 1980. SO_2 emissions have increased erratically from 10×10^6 tons (1900) to a high of 32×10^6 tons in 1970. Major decreases in SO_2 emissions occurred as a result of the Depression, the end of World War II, and the passage of the Clean Air Act. VOC emissions trends are similar to those of NO_x, with an additional major downturn in 1975. GNP and population are plotted as examples of social and economic trends which link and affect emissions trends in the U.S. Many additional factors, such as the growth of the electric utility and automobile industries and the use of natural gas fuels, need to be considered to fully understand or project these trends.

Figures 2, 3, and 4 present the historic data for SO_2, NO_x, and VOC, respectively, broken down by major categories. Industrial sources include industrial boilers, space heaters, and industrial process (non-combustion) emissions. Commercial/residential includes all fuels used in these sectors.

Highway vehicles reflect both gasoline and diesel powered highway motor vehicles. The other category includes other transportation sources (vessels, railroads, off-highway), smelters, wildfires, and miscellaneous sources.

Industrial emissions dominated total SO_2 until 1950 (Figure 2). Since that time, utilities have accounted for a rapidly growing proportion, reaching about 75 percent in 1980. The other three major sectors have all shown declining SO_2 emissions since 1945. Figure 3 shows that NO_x emissions have increased steadily since 1900, dipping only during the Depression. The increase has principally resulted from the growth of utility and highway vehicle emissions. Figure 4 shows that the VOC emissions trend is the result of three major sectors varying independently.

Fuel Use

Both increased total fuel use and changes in the types of fuels used greatly affect emissions. Figure 5 shows that total coal consumption has varied little since 1910, but has shown a steady, slow increase since 1960. Natural gas consumption has risen dramatically since 1935, and has contributed significantly to the similar trend in NO_x emissions. Wood combustion has decreased in both absolute and relative terms since 1900. The oil category includes residual and distillate oil, but does not include gasoline and diesel fuels. Gasoline and diesel fuels are shown as a separate category in Figure 5.

Stack Height

Emissions exit height is one of the important parameters affecting the transport of pollutants in the atmosphere. These data are available from the historic inventory (Figures 6 and 7) in four broad categories: less than 120 feet, 120 to 240 feet, 240 to 480 feet, and more than 480 feet. The first class includes ground level emissions and the last the tallest stacks. Exit velocities and temperatures are not in the historic inventory.

SO_2 and NO_x emissions distributions by stack height show the trend toward taller stacks. For SO_2, emissions prior to 1920 primarily came from stacks less than 120 feet. Beginning in 1920, SO_2 emissions from the two tallest categories increased in relation to those from the smaller stacks. As of 1980, more than 30 percent of SO_2 emissions are from stacks of 480 feet or taller, and over 70 percent of SO_2 emissions are from stacks taller than 240 feet. NO_x emissions continue to be dominated by ground level sources, although the proportion has dropped from 83 percent in 1900 to 53 percent in 1985. Since 1950, the growth in proportional distribution has been in the tallest stacks.

1985 Detailed Emissions Inventory

This section presents an overview of combustion emissions reported in the 1985 NAPAP anthropogenic emissions inventory. The detailed inventory provides much greater source resolution than the historic inventory, including data for discrete point sources (e.g., stacks) and for 100 categories of area sources for each U.S. county. Emissions data from the 1985 detailed emissions inventory are based on a preliminary summary of the data base. These data have

since been reviewed by the states as a final quality assurance step. Revisions based on this review will be reflected in the final 1985 anthropogenic emissions inventory.

The differentiation between point and area sources is fundamental to the structure of the detailed data base. Figure 8 shows how each of the three pollutants is divided between point and area sources. This figure includes non-combustion emissions, which are large contributors only for VOC. The figure shows that point sources account for 90 percent of SO_2, NO_x emissions are divided nearly equally between point and area sources, and over 90 percent of VOC emissions are from area sources. The largest major sectors for combustion emissions are utilities, industrial (i.e., smelters, iron and steel, refineries), and transportation (highway) emissions (Table 2).

The largest single SO_2 emissions sector is utilities. These units contribute 15.6×10^6 tons of SO_2. Distribution of SO_2 emissions among all major sectors is shown in Figure 9. The transportation sector accounts for over 43 percent of total NO_x emissions (8.8×10^6 tons). Utilities contribute about 32 percent (6.7×10^6 tons). Figure 10 shows the distribution of NO_x emissions among major categories. While combustion sources totally dominate SO_2 and NO_x emissions, they account for only 59 percent of VOC emissions. Nearly 65 percent of combustion VOC emissions are from transportation sources, and more than 25 percent are from commercial and residential combustion (these are principally from residential wood combustion).

Utility Sector Emissions

Utilities emit SO_2 and NO_x principally from coal-fired external combustion boilers, with oil-fired and gas-fired combustion turbines also contributing some emissions. More than 4600 utility boilers among 864 utilities are represented individually in the 1985 inventory. (Emissions from cogeneration units are included in the Industrial Sector Emissions category.)

Utility SO_2 and NO_x emissions by major fuel types are presented in Figure 11. Coal emissions include anthracite, bituminous, sub-bituminous, and lignite coal firing. Oil emissions include residual and distillate oil. Coal-fired boilers account for 95 percent of total utility SO_2 and 87 percent of total utility NO_x emissions.

Figure 12 shows the spatial distribution of utility generating stations with very large SO_2 emissions in 1985. The 50 stations illustrated in this figure account for approximately 50 percent of all utility SO_2 emissions for 1985. Figure 13 shows the spatial distribution of utility generating stations with large NO_x emissions in 1985. These 69 stations account for approximately 50 percent of all utility NO_x emissions for 1985.

Industrial Sector Emissions

Two parallel strategies have been employed to analyze industrial emissions. First, point sources are aggregated into combustor types: boilers, internal combustion, process heaters, furnaces, and incinerators. Second, point sources are aggregated into major industry types: paper, oil and gas, smelters, iron and steel, cement, chemicals, and other. The detailed inventory

contains both a Source Classification Code (SCC) and a Standard Industrial Classification (SIC) for each point source to allow this analysis.

Table 3 shows a breakdown of industrial combustion emissions by combustor type, and Table 4 shows a breakdown of the same emissions by industry. Figure 14 shows that Oil and Gas Extraction and Refining, Ore Smelters and Iron and Steel Mills, and Pulp and Paper Mills are the largest industrial sources of SO_2 emissions. These industries burn fuel, byproducts, or process intermediates containing sulfur contaminants. Figure 15 shows the distribution of industrial NO_x combustion emissions among the industries. Note that the smelting segment accounts for a smaller portion of NO_x than it did for SO_2. This is because the smelter SO_2 emissions in Figure 14 reflect the oxidation of sulfide in the ores as well as fuel combustion emissions. Figures 16 through 20 show the locations of the largest SO_2 emitting plants for the major industries identified. Figures 21 through 25 show the locations of the largest NO_x emitting plants in those industries.

Overall Fuel Use Comparison

Overall U.S. fuel consumption for 1985 reveals that coal is the largest energy source with natural gas nearly as large. Coal combustion emits principally SO_2, while natural gas emits primarily NO_x. The use of these two fuels impacts SO_2 and NO_x emissions to the greatest extent.

Emissions By Stack Height

The importance of release height to acid deposition models made collection of stack parameters a high priority for the 1985 inventory. Figure 26 shows the magnitude of SO_2 and NO_x for four stack height ranges. It should be noted that this figure is for point sources only, and is therefore not comparable to Figures 6 and 7. Area sources account for about half of all NO_x emissions, and almost all of these emissions would be at the ground level (less than 120 feet). This figure does show that the bulk of point source SO_2 emissions are emitted above 240 feet, while point source NO_x emissions are more evenly distributed vertically.

CONCLUSIONS

Combustion categories are the most significant sources of anthropogenic SO_2 and NO_x emissions. Utilities contributed nearly 70 percent of the 1985 anthropogenic emissions of SO_2. The two major sources of NO_x in 1985 were utilities and the transportation sector. On the other hand, VOC emissions in 1985 came from combustion and non-combustion sources, principally evaporative fugitive sources, in approximately equal amounts.

Detailed conclusions on specific emissions sources cannot be drawn from the trends data or the single year of detailed emissions presented in this paper, but two important points can be noted. First, emissions from combustion sources must be interpreted in conjunction with information about the transport of those emissions. Long-range transport significantly affects how emissions potentially impact the environment. Second, the data indicate that the Clean

Air Act of 1970 coincides with a dramatic shift in the historic trend of SO_2 emissions.

Emissions trend analyses and detailed emissions inventories provide the tools necessary to begin the assessment of the fate and impacts of emissions in the environment. The data presented here are representative of a much larger volume of detailed emissions data for all of the source categories and industrial processes in the detailed emissions inventories. There is a substantial body of emissions test data for most of these categories that indicates individual chemical constituents to be expected from those processes and unit operations.

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CONVERSION FACTORS

Readers more familiar with the metric system may use the following to convert to that system:

English Units	Multiplied by	Equals Metric
Btu	1055	Joules
Foot	0.3048	Meter
Ton	0.9072	Metric Ton

TABLE 1. SPECIFICATIONS FOR THE HISTORIC EMISSIONS TRENDS AND 1985 DETAILED EMISSIONS DATA BASES

SPECIFICATION	HISTORIC	1985 DETAILED
Geographic Domain	Contiguous U.S.	Contiguous U.S.
Species	SO_2, NO_x, VOC	SO_2, NO_x, VOC, PM, CO Primary SO_4, HF, HCL, NH_3
Spatial Resolution	State	Emission Point (Point Source) County (Area Source)
Temporal Resolution	Annual/Five-Year	Seasonal/Annual
Source Resolution	Major Sectors	3300 Point Source Classes 100 Area Source Classes
Uses	Trend Analysis	Assessment Research Effects Research Projections

TABLE 2. 1985 ANTHROPOGENIC EMISSIONS BY MAJOR CATEGORY (10^3 TONS)

Major Category	SO_2	NO_x	VOC	PM	CO
Utility Combustion	15,590	6,659	58	49[illegible]	367
Transportation	864	8,834	7,350	4,428	42,697
Industrial Combustion	3,729	2,358	375	635	2,359
Commercial/Residential Combustion	571	689	3,037	1,529	8,899
Other Combustion	572	712	591	715	4,360
TOTAL COMBUSTION (ALL SOURCES)	21,326	19,252	11,411	7,797	58,682
TOTAL ANTHROPOGENIC EMISSIONS	22,404	20,505	22,387	36,913	63,375

TABLE 3. 1985 U.S. INDUSTRIAL EMISSIONS BY COMBUSTOR TYPE (10^3 TONS)

Combustor Type	SO_2	NO_x	VOC	PM	CO
Coal Boilers	1,147	398	5	108	74
Oil Boilers	476	167	6	63	38
Gas Boilers	137	392	27	17	228
Oil Internal Comb.	2	12	5	1	52
Gas Internal Comb.	5	576	71	5	107
Process Heaters, Dryers, Kilns	914	563	87	298	1,103
Metallurgical Furnaces & Ovens	642	125	74	18	527
Incinerators & Flares	376	23	27	11	58
Miscellaneous Fuel Boilers	31	101	63	113	173
TOTAL INDUSTRIAL COMBUSTION	3,730	2,357	365	**634**	2,360
TOTAL COMBUSTION (ALL SOURCES)	21,326	19,252	11,411	7,797	58,682
TOTAL ANTHROPOGENIC EMISSIONS	22,404	20,505	22,387	36,913	63,375

TABLE 4. 1985 INDUSTRIAL EMISSIONS BY INDUSTRY SECTOR (10^3 TONS)

Industry	SO_2	NO_x	VOC	PM	CO
Pulp & Paper Mills	603	278	91	144	767
Refineries	576	301	87	59	459
Oil & Gas Extraction	259	296			
Copper, Lead, & Aluminum Smelt	459	9	138	218	369
Iron & Steel Mills	208	105			
Cement Manufacturing	274	130	1	52	6
Industrial Organic Chemicals	162	161	10	29	33
Industrial Inorganic Chemicals	94	39			
Other	1,095	1,038	38	133	726
TOTAL INDUSTRIAL COMBUSTION	3,730	2,357	365	635	2,360
TOTAL COMBUSTION (ALL SOURCES)	21,326	19,252	11,411	7,797	58,682
TOTAL ANTHROPOGENIC EMISSIONS	22,404	20,505	22,387	36,913	63,375

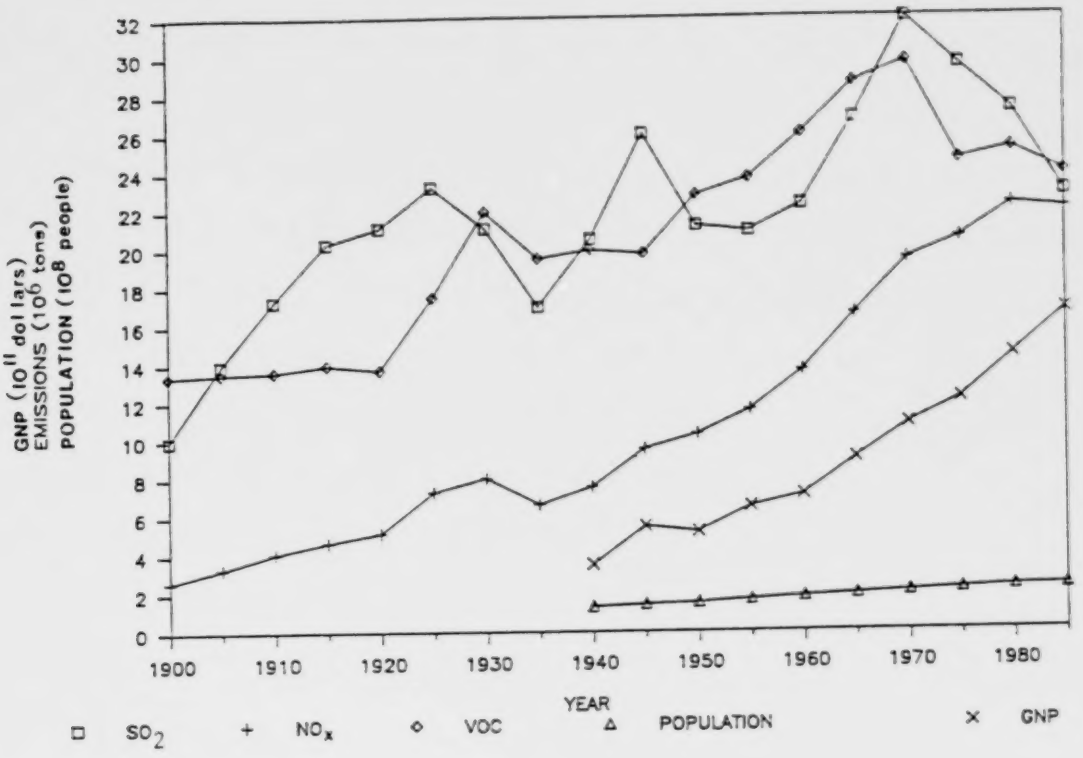

Figure 1. Historic U.S. emissions of SO_2, NO_x, and VOC.

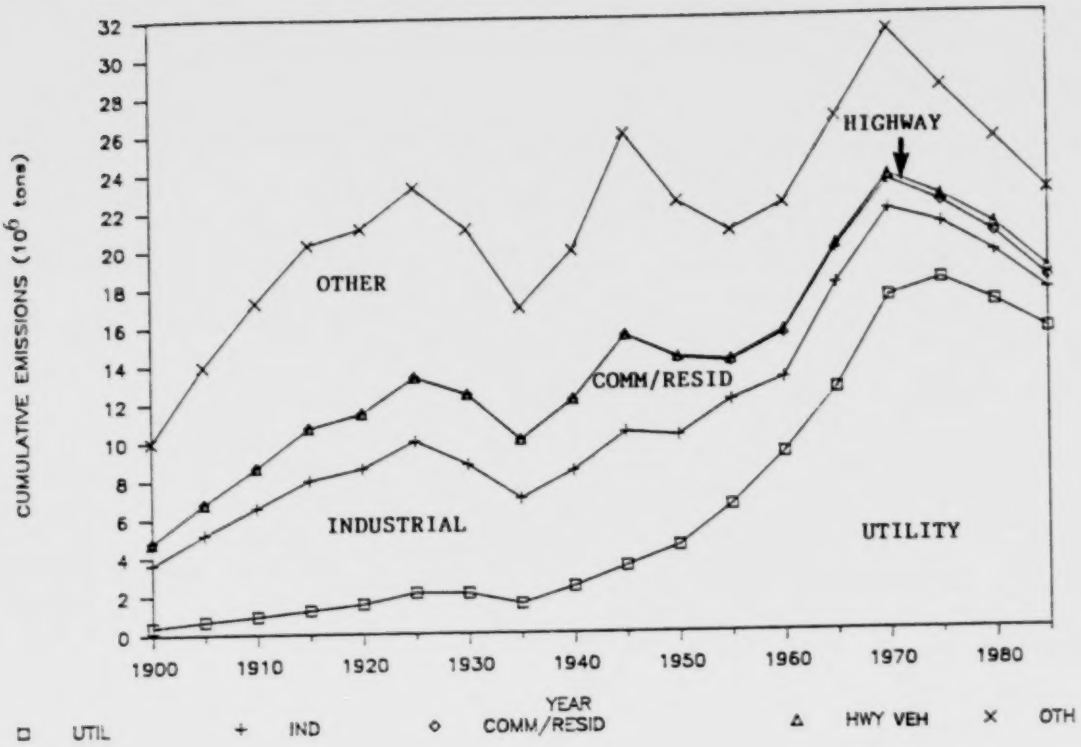

Figure 2. U.S. SO_2 emissions by major category: 1900–1985.

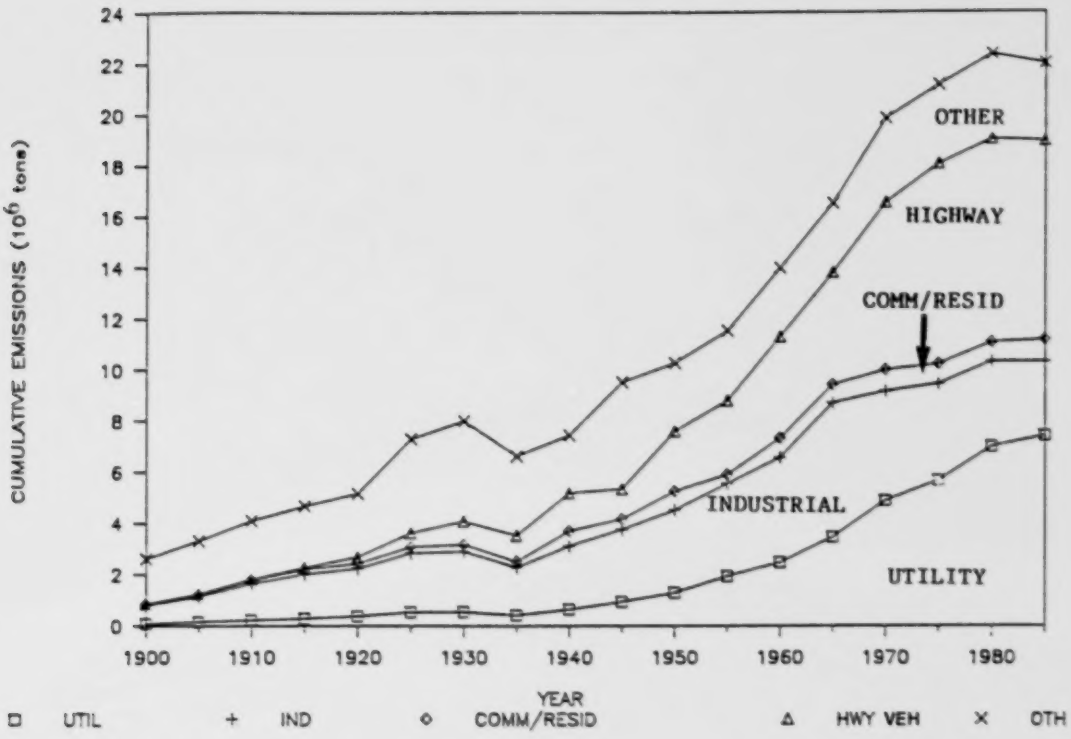

Figure 3. U.S. NO_x emissions by major category: 1900–1985.

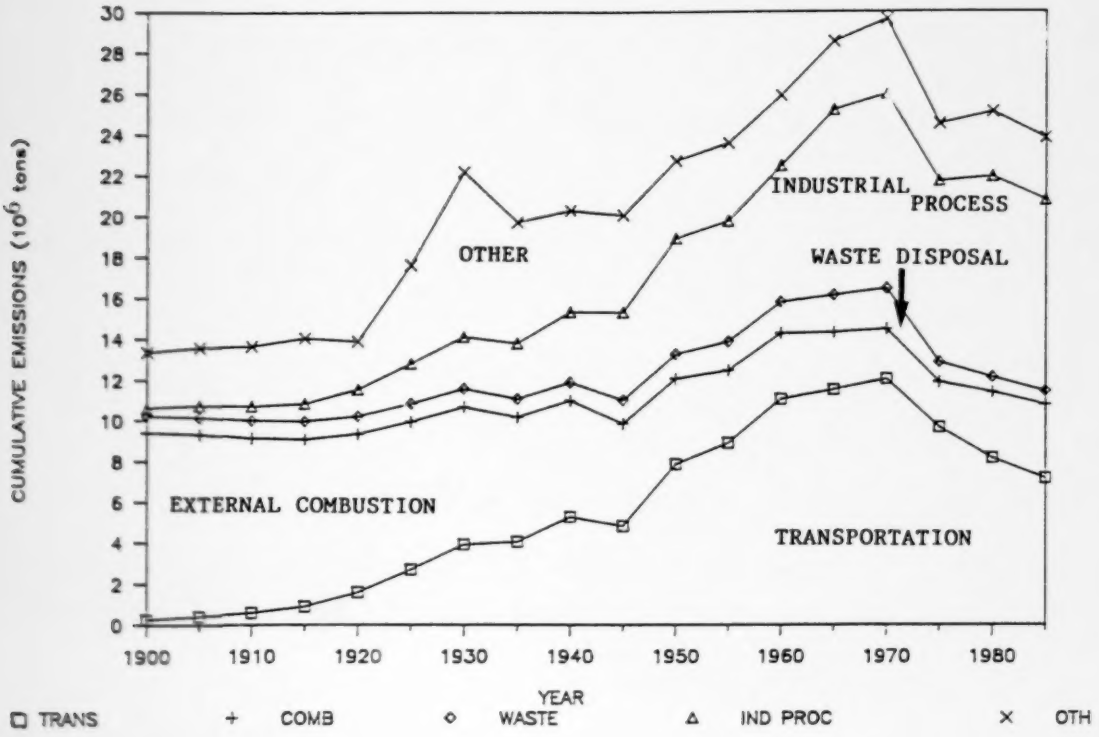

Figure 4. U.S. VOC emissions by major category: 1900–1985.

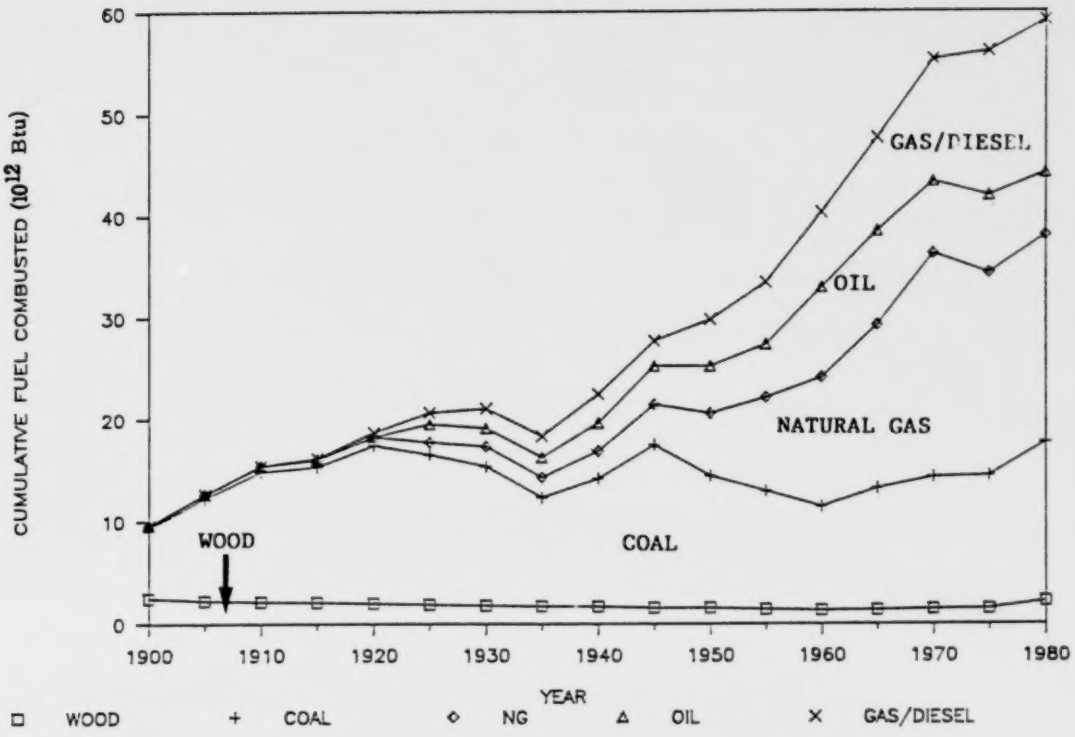

Figure 5. Historic fuel use by fuel type.

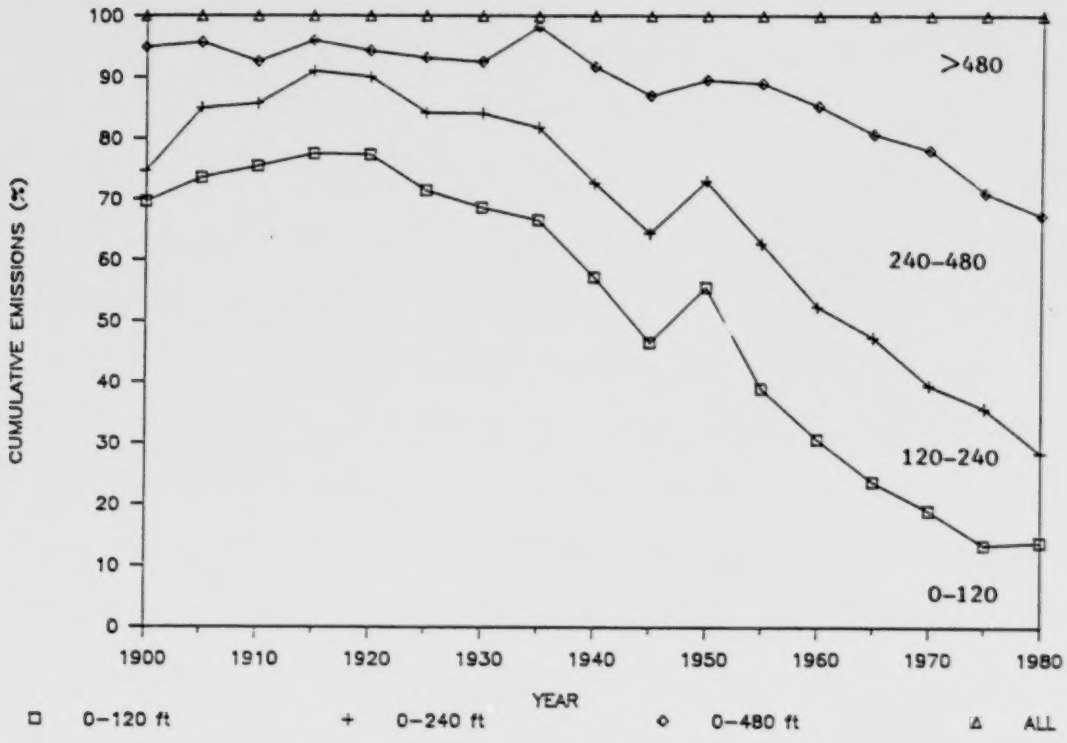

Figure 6. U.S. SO_2 emissions by stack height: 1900–1980.

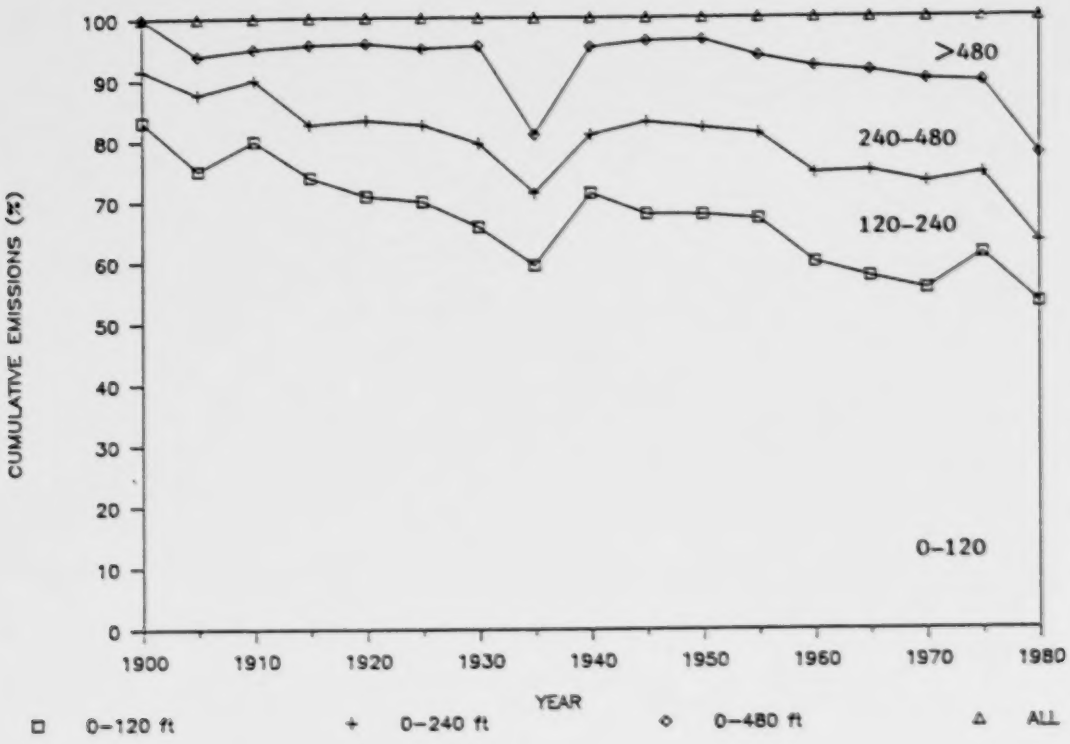

Figure 7. U.S. NO_x emissions by stack height: 1900-1980.

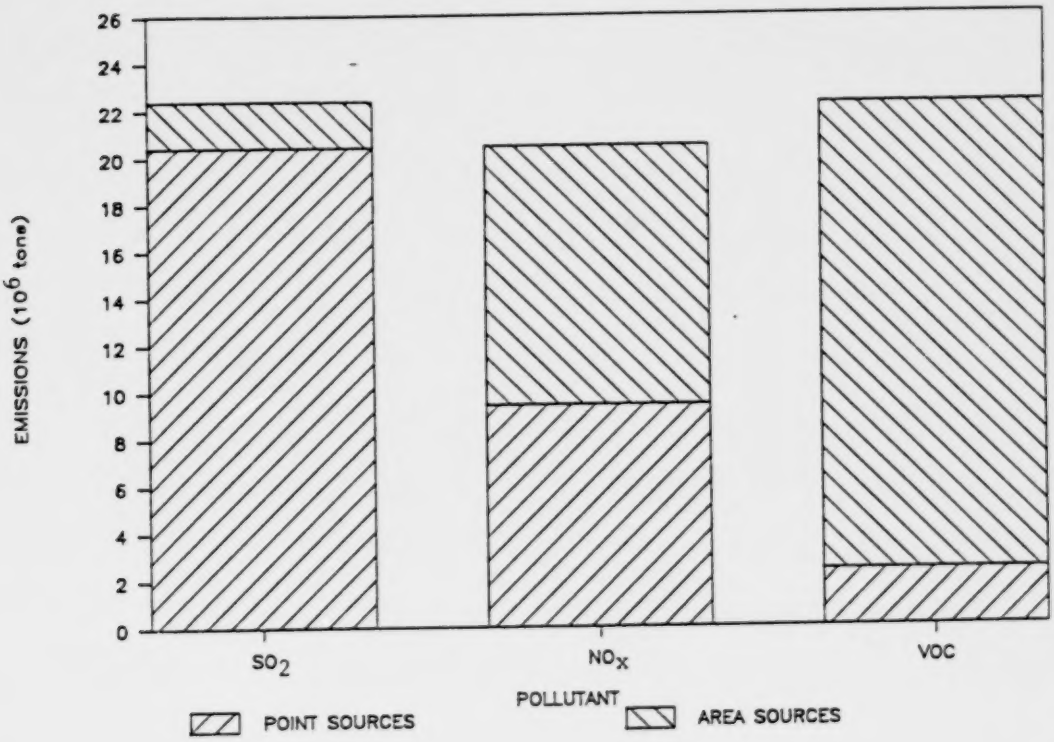

Figure 8. Total 1985 anthropogenic emissions from point and area sources.

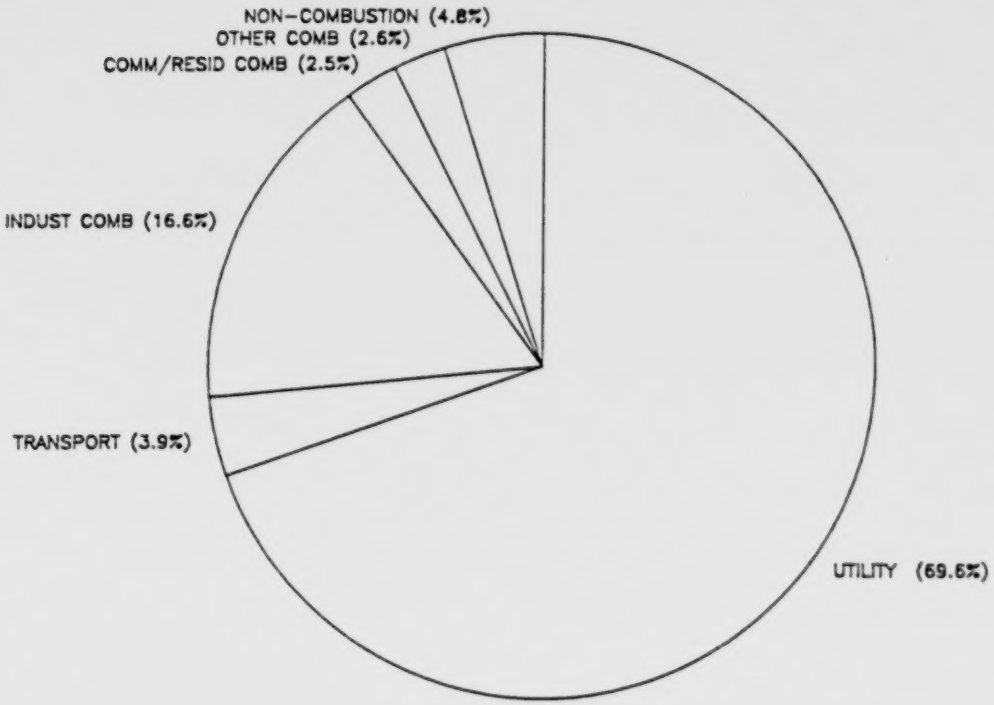

Figure 9. Distribution of 1985 U.S. SO_2 emissions by major category.

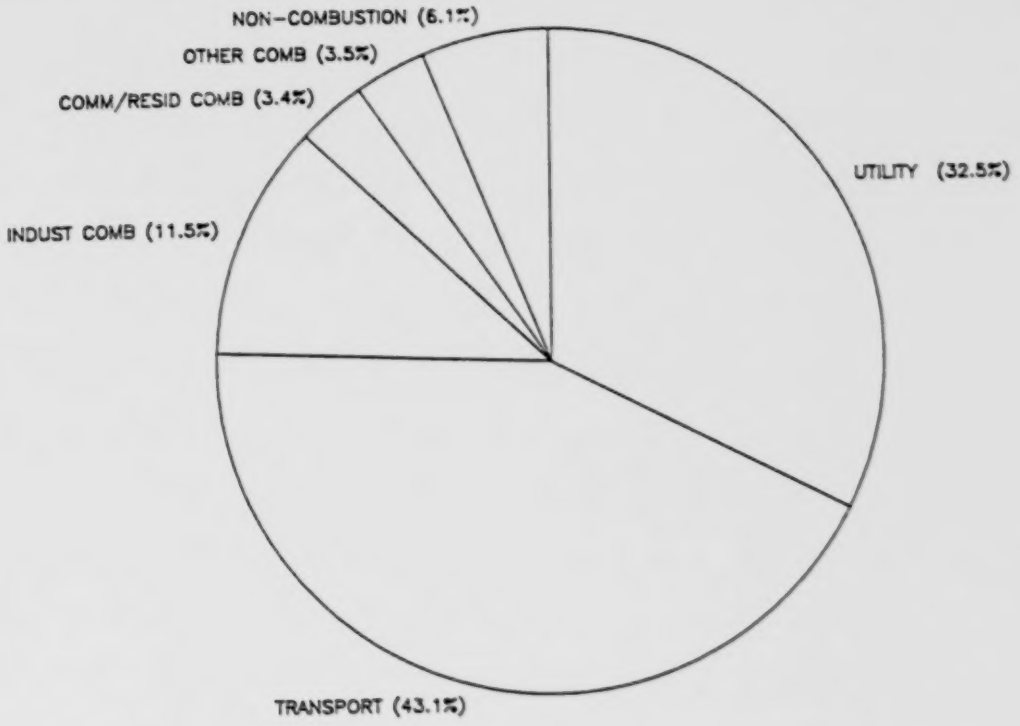

Figure 10. Distribution of 1985 U.S. NO_x emissions by major category.

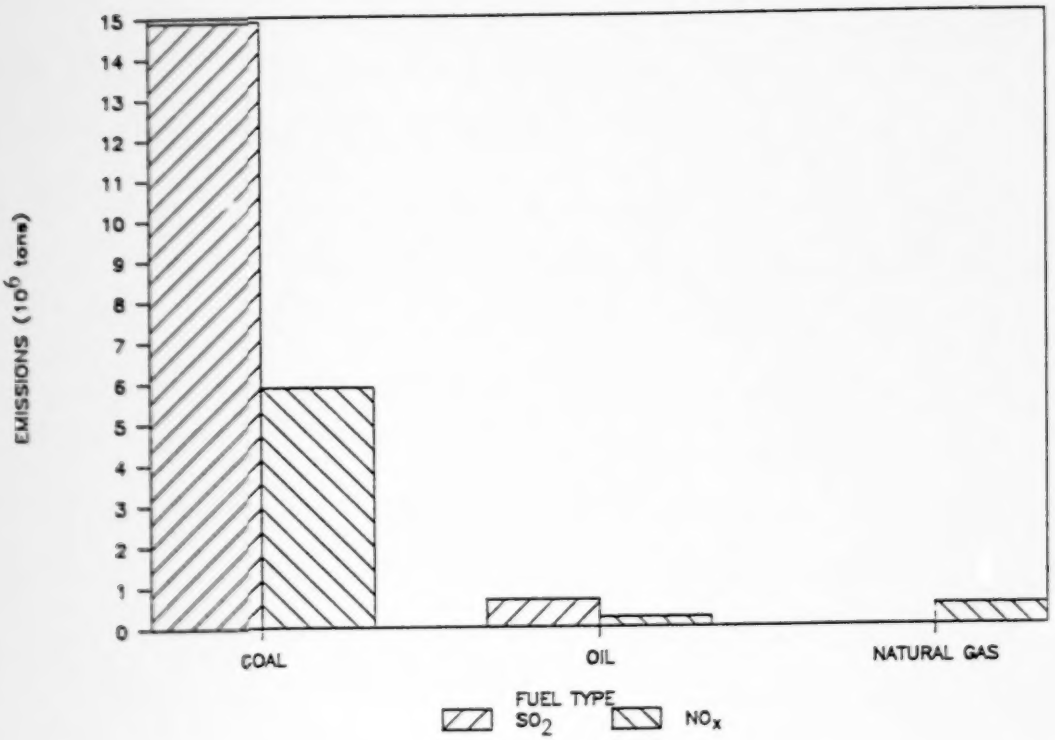

Figure 11. 1985 utility SO_2 and NO_x emissions by fuel type.

Figure 12. Spatial distribution of selected electric utilities with large SO_2 emissions.

Figure 13. Spatial distribution of selected electric utilities with large NO_x emissions.

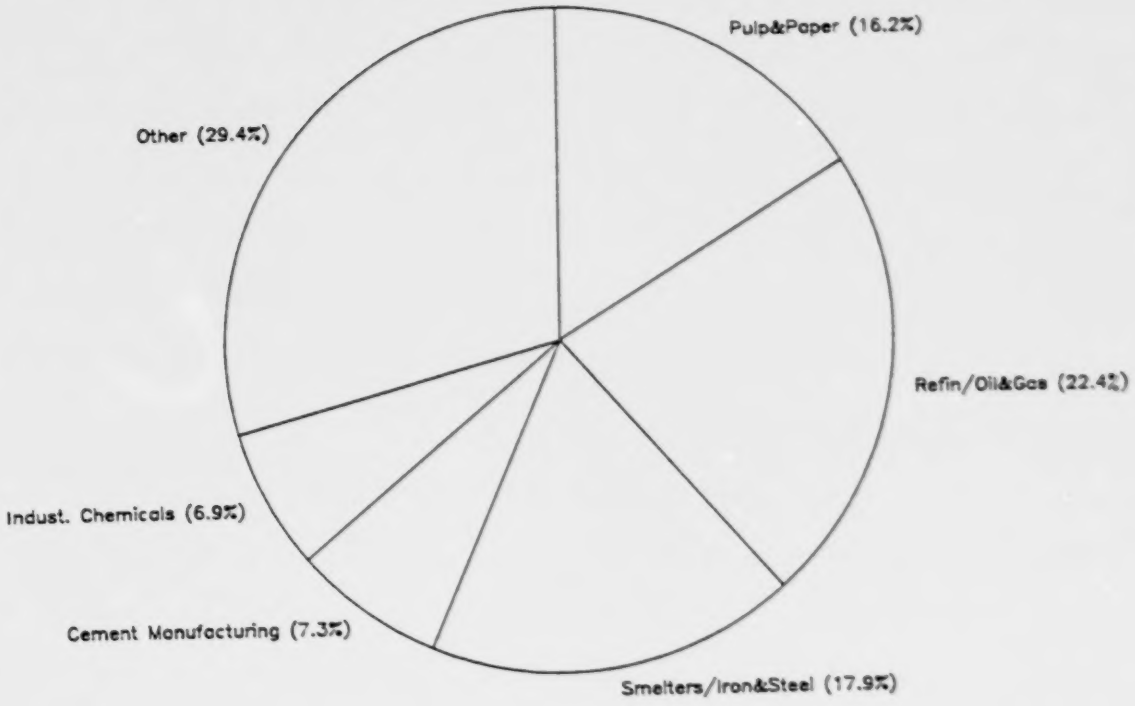

Figure 14. 1985 U.S. industrial combustion SO_2 emissions by six sectors.

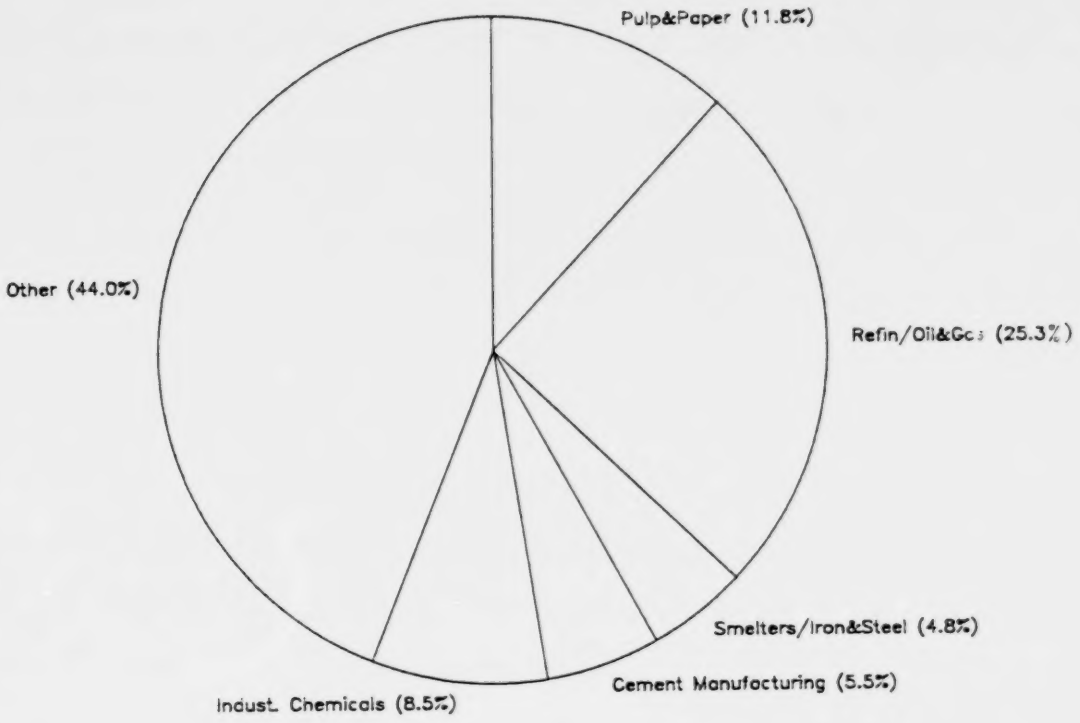

Figure 15. 1985 U.S. industrial combustion NO_x emissions by six sectors.

Figure 16. Spatial distribution of pulp and paper mills with large SO_2 emissions.

Figure 17. Spatial distribution of oil and gas extractors and refineries with large SO_2 emissions.

Figure 18. Spatial distribution of smelters and iron and steel mills with large SO_2 emissions.

Figure 19. Spatial distribution of cement manufacturers with large SO_2 emissions.

Figure 20. Spatial distribution of chemical manufacturers with large SO_2 emissions.

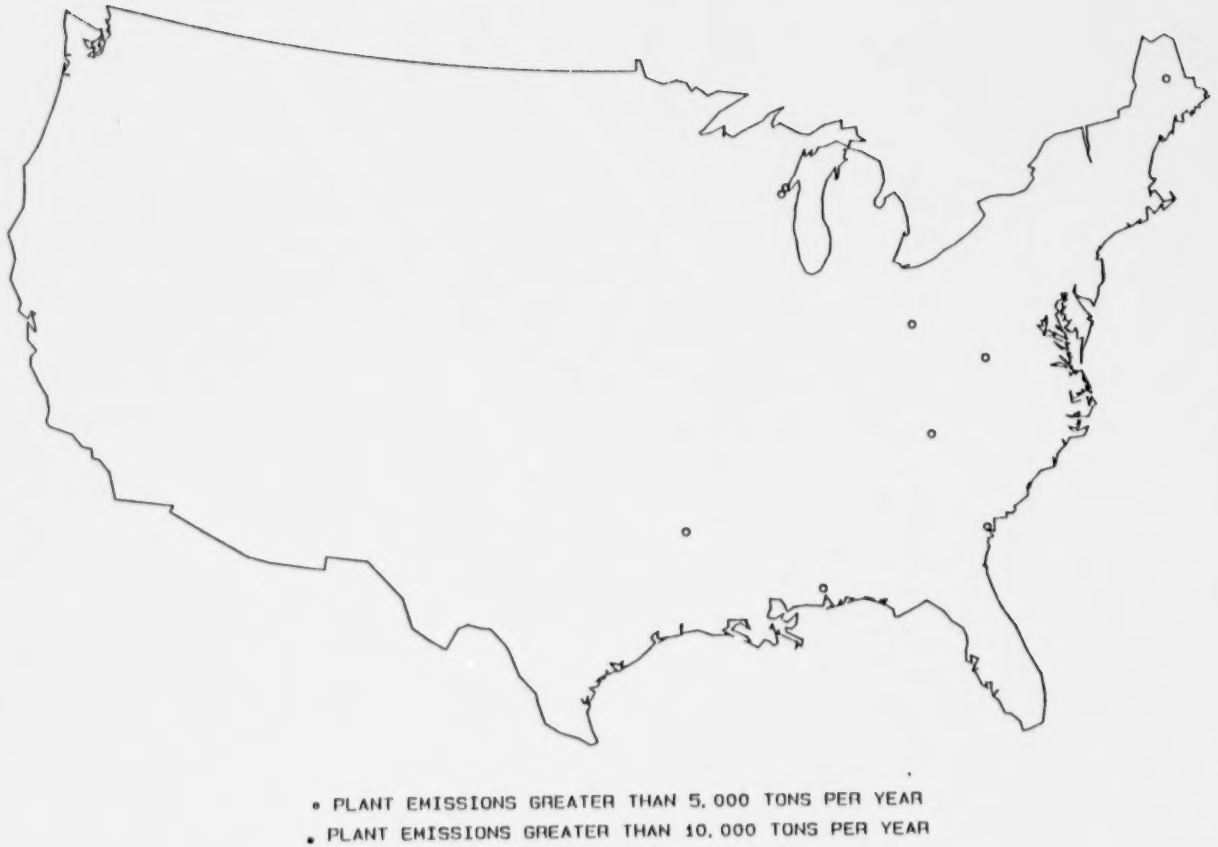

Figure 21. Spatial distribution of pulp and paper mills with large NO_x emissions.

Figure 22. Spatial distribution of oil and gas extractors and refineries with large NO_x emissions.

Figure 23. Spatial distribution of smelters and iron and steel mills with large NO_x emissions.

Figure 24. Spatial distribution of cement manufacturers with large NO_x emissions.

Figure 25. Spatial distribution of chemical manufacturers with large NO_x emissions.

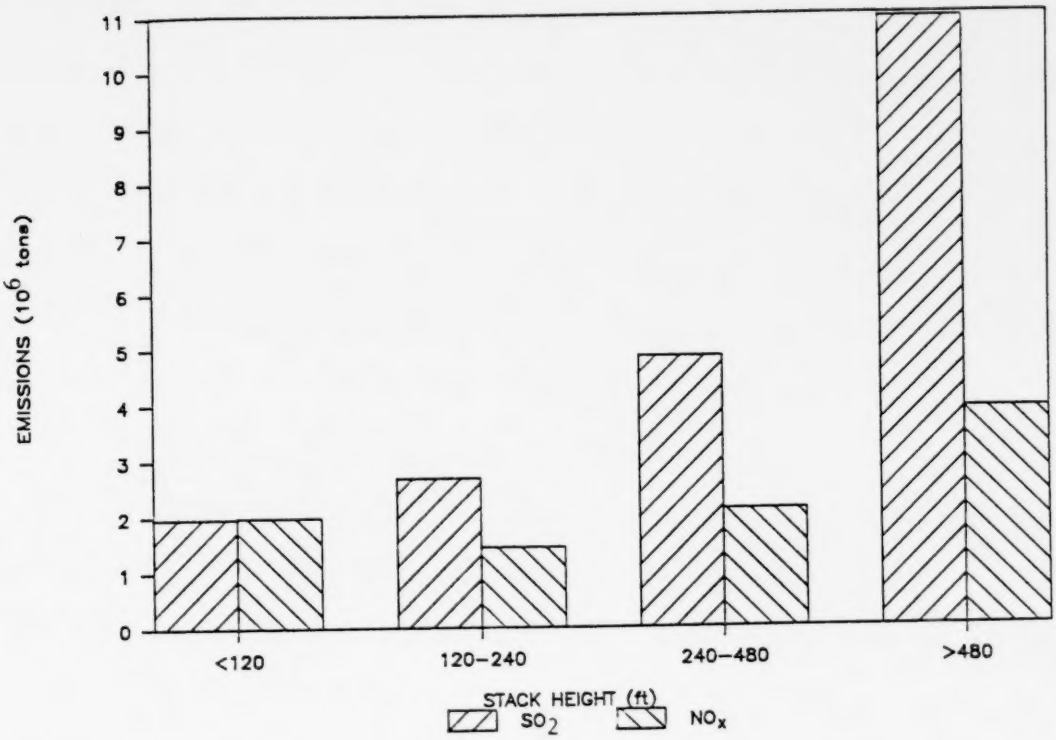

Figure 26. 1985 U.S. emissions of SO_2 and NO_x by stack height.